

Original article

Changing values of lake ecosystem services as a result of bacteriological contamination on Lake Trzecieko and Lake Wielimie, Poland

Małgorzata Cichoń

Department of Geoecology, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Krygowskiego Str. 10B, 61-680 Poznań, Poland
E-mail address: cichon@amu.edu.pl

ABSTRACT

Lake ecosystems, on the one hand, are affected by tourism, and on the other by development for tourism. Lake ecosystem services include: water with its self-cleaning processes, air with climate control processes, as well as flora and fauna. Utilisation of services leads to interventions in the structure of ecosystems and their processes. Only to a certain extent, this is specific to each type of environmental interference, remains within the limits of ecosystem resilience and does not lead to its degradation. One of the threats is bacteriological contamination, for which the most reliable sanitation indicator is *Escherichia coli*. In lake water quality studies it is assumed that the lakeshore cannot be a source of bacteria. It has been hypothesised that the problem of bacterial contamination can be serious for the places that do not have any infrastructure, especially sanitation. Consequently, the purpose of the study was to determine the extent to which lakeshore sanitation, in particular the level of bacteriological contamination, has an impact on the value of services provided by the selected lake ecosystems (Lake Trzecieko and Lake Wielimie – Szczecinek Lake District). Five selected services related to lake ecosystems are: water, control over the spread of contagious diseases, aesthetic values, tourism and recreation, as well as the hydrological cycle with its self-cleaning function. Services, as well as the criteria adopted for evaluation, allow us to conclude that the services provided by the lake ecosystems are suitable to fulfill a recreation function. However, the inclusion of quality criteria for sanitary status has shown that the value of system services has dropped by as much as 50%. Value changes are visible primarily for water and aesthetic qualities. Such a significant decrease in the value of services clearly indicates the importance of the sanitary conditions of lakes and their appropriate infrastructure. In view of the valuation proposals, there is a problem of uncertainty of valuation of ecosystem services.

KEY WORDS: ecosystem services, lakes, sanitation, recreation utility

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1. Introduction

The natural environment is constantly being pressurised by socio-economic systems. Both economic and social growth are possible only when they are supported by ecosystems and their services (BURKHARD ET AL., 2005). Using such services leads to interference into structures and processes of ecosystems. However, there is a certain degree, characteristic to a given type of environment, to which ecosystems are resistant to such changes leading to degradation of ecosystem. Crossing such a border leads to negative changes in an ecosystem – decreasing the amount and quality of ecosystems.

The changes in ecosystem services caused by people may be unveiled to a different extent, depending on the category of service (BRAAT & TEN BRINK, 2010). Lake ecosystems are particularly susceptible to changes in service delivery.

Microbiological contamination makes the current state of the world's lakes alarming. A growing number of scientists are talking about the integrated management of lake catchments (NAKAMURA, 1997) and the sustainable use of lake resources (ENGEL, 1987). One of the threats is bacteriological contamination, for which *Escherichia coli* is one of the most reliable indicators of water quality (BITTON, 2005). It has been estimated that even up to 30%

of bacteria that are present in water reservoirs result from agriculture (e.g. surface runoff and the use of farmyard manure) and leaky sewage systems. Researchers have taken it for granted that the littoral zone, including the beach and the adjacent infrastructure, could not constitute a source of bacteria. However, bacterial pollution of places that have no infrastructure, especially a sanitary one, can pose a real problem. The problem of shore pollution can be especially hard to solve because, as research from the last 40 years has shown, faecal coliform bacteria and *Escherichia coli* can survive outside a living organism longer than it was previously assumed (BYAPPANAHALLI ET AL., 2003). Bacteriological contamination might occur on a beach or the area adjacent to it due to the dynamic character of lake shore zones.

The aim of this study is to determine the extent to which the sanitary condition of the lakeshore, especially the level of bacterial contamination, affects the value of services provided by the lake ecosystem. Due to an emphasis on cultural services, including recreation, the processes and phenomena occurring in the littoral zone of the lake will be of critical importance in the article. Within this study, the lakeshore zone consists of the littoral, lake terrace with a beach and terrace edge along with the forest/park surroundings.

2. Research area and methods

In order to identify changes in the level of ecosystem services provided as a result of the recreational use causing bacterial contamination, two lakes in NW Poland were selected for the research. These were Lake Trzesiecko (channel lake) and Lake Wielimie (melt-out lake), located on the northern slope of the frontal moraine ridge of Middle Pomerania, in the Szczecinek Lake District as delimited by KONDRACKI (2011). The lakes are connected to each other by the River Nizica, which flows from Lake Trzesiecko situated within the town of Szczecinek. At the end of the 18th century, after numerous floods in Szczecinek caused mainly by the outflows of Lake Trzesiecko, the water level in both lakes was lowered through hydrotechnical work. As a result, the south-west Wielimie lakeshore gradually changed into extensive quakes, and the lake became inaccessible from the town. The River Gwda also flows into Lake Wielimie (Fig. 1).

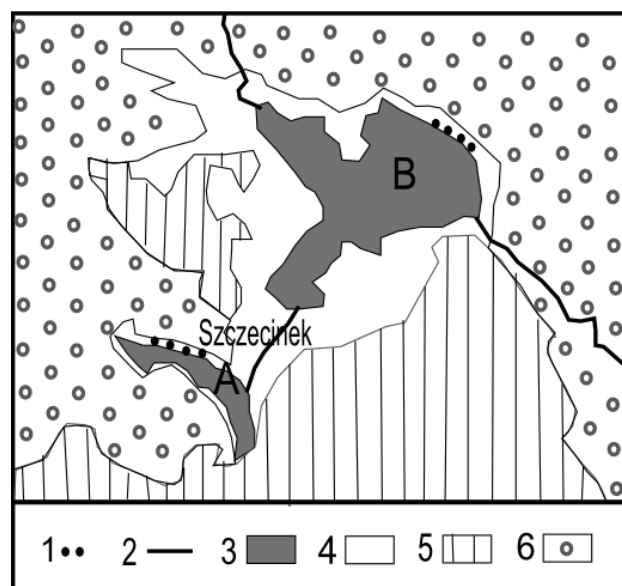


Fig. 1. The geomorphology of the study area: A – Lake Trzesiecko, B – Lake Wielimie

1 – beach, 2 – river, 3 – lake, 4 – kettles, 5 – morainic plateau of the Pomeranian Phase, 6 – outwash (based on Maksiak & Mróz, 1978)

On the lake's north-eastern shore, there is a swimming area (53°42'N, 16°40'E) with a typical artificial urban beach in the centre of the city of Szczecinek. Sand is the predominant surface type (220 m²), the lake is enclosed by a belt of park trees. Portable toilets, playgrounds as well as walking and biking routes are located near the beach. In 2012, the Ecological State Macrophyte Index (ESMI) for Trzesiecko lake equalled 0.31 and according to the currently enforced regulations, this result falls within the ranges of good ecological status of water in the 2nd water quality class (HEESE ET AL., 2012). Seasonally, the presence of blue-green algae is observed, and nitrogen and phosphorus levels are exceeded.

In the eastern part of Lake Wielimie (Fig. 2), 1.5 km from the village of Gwda Wielka, there is the only one in this area (53°75'N, 16°77'E) is a natural sandy beach of 400 m². Each year, the District Environmental Protection Inspectorate indicates that water quality is outside the permissible levels, this area is not authorised for use, which does not prevent local residents from swimming in the lake. *Salix alba* L. grows along the beach, and further on there is wasteland used as a car park. Similar to other lakes, the infrastructure consists of a pier, benches and litterbins.

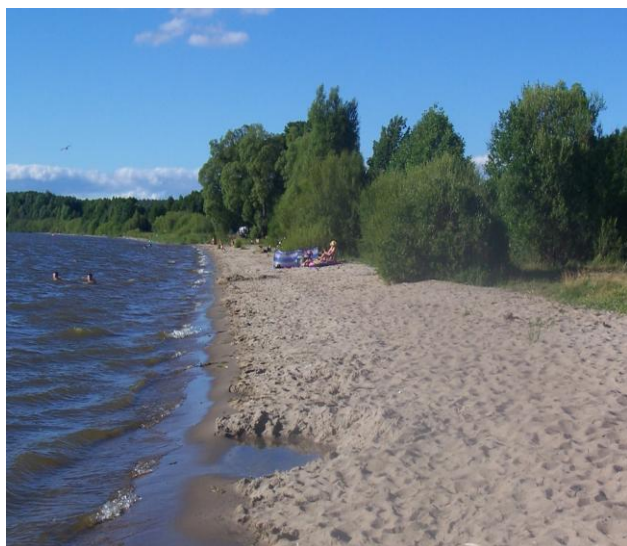


Fig. 2. Structure of a littoral zone: the example of Lake Wielimie (M. Cichoń)

Recognition of changes in the value of services provided by lake ecosystems began with selecting five services related to lake ecosystems. The study adopted the typology of ecosystem services introduced by the *Millennium Ecosystem Assessment*. These five ecosystem services are: water, control over the spread of contagious diseases, aesthetic values, tourism and recreation, as well as the hydrological cycle with a self-cleaning function. Each of these services was analysed using a four-scale evaluation (Table 1) in line with earlier research by BERNACIAK & CICHON (2012) and then, based on the results of the bacteriological contamination, new criteria for the valuation of recreational services of lakes were created. The results of the bacteriological contamination survey of the lakeside areas were taken into account in the assessment of ecosystem services.

Table 1. Number of *E. coli* bacteria on the beach [jtk/100 ml deposit]

Lake	June	July	August	September
Wielimie	18	960	960 000	372
Trzesiecko	4 800	92 000	1 840 000	1 840 000

2.1. Sampling

Samples of water, sand and soil were taken from five littoral zones of the lakes in 2014. A total of 60 samples were examined. A sample of sediments from the sandy area was obtained by collecting 1.5 g of material in a grid of squares of 1-metre side length and placing it in a 250-ml sterile glass container. Each of the 20 samples was taken at a depth of up to 5 cm using a disposable plastic spoon (GARZIO-HADZICK ET AL., 2010). Subsequently, the samples were bulked to make a single composite sample of 30 g. The same procedure was followed to collect soil samples from the areas surrounding the beach. Because of the pilot character of this study, the samples were mixed in a manner similar to the one adopted by OLAŃCZUK-NEYMAN & JANKOWSKA (2001) and ISHII ET AL. (2007).

2.2. Microbiological analyses

Microbiological analyses were used to determine bacteria of the coliform group and thermotolerant coliforms (which comprise mainly *Escherichia coli*) using a multiple-tube fermentation method (in accordance with the ISO 9308-2:2012 standard).

3. Bacterial contamination of the lake water, beach and surroundings

The study of lake water quality revealed that the level of faecal coliform bacteria (FC), which should not exceed 100 in 100 ml of water, was surpassed. In 2014 this figure was exceeded once in Lake Wielimie (in July), where the level exceeded the norm by almost five fold. The number of faecal coliform bacteria (FC) also reached the permissible limit twice in Lake Wielimie and once in Lake Trzesiecko (Fig. 3). Due to bacterial contamination of water, Lakes Trzesiecko and Wielimie, should not have been used for recreational purposes, while the Lake Wielimie beach, despite the lack of official permission for swimming, recorded over ten thousand people, of whom 25% swam.

Studies of the seasonal occurrence and level of faecal coliform bacteria (FC) on the beaches showed an upward tendency from June to August, with the peak level being recorded in August 2014 (Table 1). Taking into consideration the entire season, the level of faecal coliform bacteria (FC) was the highest in August in the beach material of the Lakes Trzesiecko (approximately 2 million bacteria) and Wielimie (approximately million

bacteria). The pollution by faecal coliform bacteria (FC) in the beach surroundings, was at a similar level, where bacteria amounted to several thousand (Table 2). The field and laboratory studies conducted in the 2014 summer season corroborated the already known fact that the level of FC in the sand was many times higher than in the water, especially in the swash zone (FRANCY ET AL., 2003), which serves as a playground primarily for children and young people.

The primary source of bacteria acknowledged in the literature are the faeces of wild birds and other animals. An analysis of *E. coli* strains made

by ISHII ET AL. (2007) showed that the period of the highest concentration of *E. coli* bacteria spread from summer until autumn. And indeed, the variety of birds: mallard (*Anas platyrhynchos*), great cormorant (*Phalacrocorax carbo*), mute swan (*Cygnus olor*), European coot (*Fulica atra*) and gulls at the studied lakes Trzesiecko and Wielimie, (with a daily mean of 10-50 birds), can be regarded as a significant source of *E. coli*. According to KSOLL ET AL. (2007), from 15 to 65-67% of all *E. coli* bacteria in water and the shore zone was associated with shore birds.

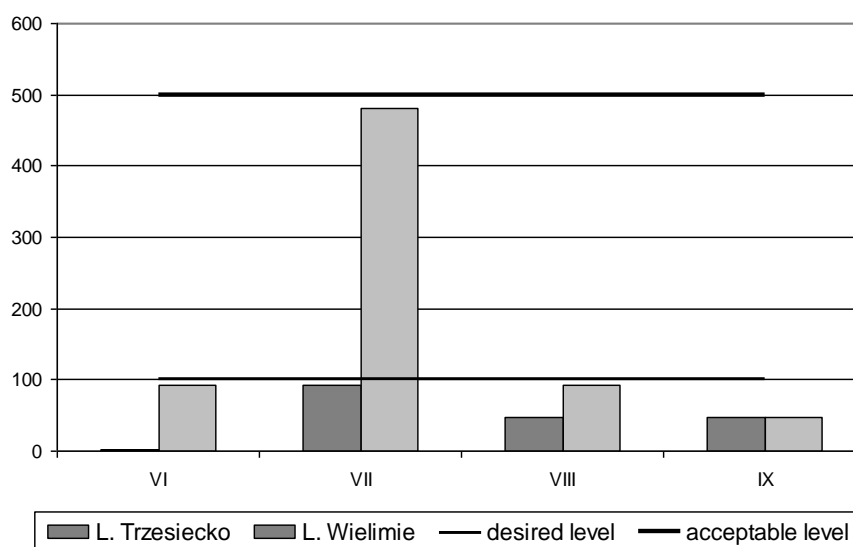


Fig. 3. Number of *E. coli* bacteria [jtk] in 100 ml water

Table 2. Number of *E. coli* bacteria in the surroundings of the lakes [jtk/100 ml deposit]

Lake	VI	VII	VIII	IX
Wielimie	4 800	300	192	960
Trzesiecko	48 000	9 600	960	19 200

It is possible that bacteria can get directly into water as a result of defecation (soiled nappies, lack of toilets), especially considering the number of people using these two above-mentioned lakes, which varies from a few to over ten thousand in a season, among whom 25 - 85% also swim. It should be kept in mind that these are the largest and most popular beaches within a radius of 25 km. PAPADAKIS ET AL. (1997) found that contamination of wet sand with *S. aureus* was correlated with the number of swimmers; the more popular a beach, the higher correlation. Accordingly, density of people on the beach is of high importance. The highest monthly density of people was recorded for the small beach and the area around Lake Trzesiecko, both in July (47 persons/m²) and August (37 persons/m²). Since the beach is

located in the city centre, there is a steady inflow of people throughout the entire summer season. Lake Wielimie also recorded a high density in July (10,2 persons/m²) and August (6,7 persons/m²).

Thus, the agricultural-urban character of the Lake Trzesiecko and Wielimie catchment can contribute significantly to the contamination of the water, beaches and the areas surrounding them. This was corroborated by studies carried out by ALM et al. (2003), which show the density of *E. coli*, *Enterococcus* and *Salmonella* bacteria in water to be lower on industrial and wooded beaches and higher on urban beaches and in agricultural catchments.

As far as young glacial areas are concerned, attention should be paid to the morphodynamic variability of the beach slope and diversity of the

soil cover. These factors, in conjunction with tourism-related activities, can cause lowering of soil strength parameters. In addition, in favorable weather conditions (excessive humidity, rainfall), a slip surface is created, which enables the land to be easily modeled by people resting on it. This subsequently leads to the movement of the soil on the slope along with the movement of bacterial populations.

4. Proposal a valuation of the services of a lake's ecosystem

Analysis of services of lake ecosystems in terms of the recreation functions was conducted by BERNACIAK & CICHON (2012). It indicates high scores

for both Lakes Trzesiecko and Wielimie (10 out of 15 points). Services as well as the criteria adopted for evaluation allow us to conclude that the services provided by the lake's ecosystem are suitable to fulfill a recreation function (Table 3).

Taking into account the results of improved standards in terms of bacteriological water contamination (Lake Wielimie) and the beach (Lake Trzesiecko), a new proposal for the valuation of services should be put forward. The level of bacterial contamination is determined, among others, by lithology and slope of the beach, the density of people on the beach, access to toilets, beach accessibility for domestic and wild animals, as well as the character of the basin.

Table 3. Pre-valuation of ecosystem services of Lakes Trzesiecko and Wielimie (based on Bernaciak & Cichoń, 2012)

No.	Service	Scale	Lake Trzesiecko	Lake Wielimie
12	Water	0 – no service, water is not drawn from the ecosystem, 1 – a few households draw water from the ecosystem, as a part of "normal usage" 2 – households draw water from the ecosystem as a part of "normal usage", several subject draw water as a part of "special" usage", 3 – water is drawn by plumbing system to meet the needs of inhabitants and industry	2	2
19	Contagious disease spread control	0 – the ecosystem contributes to the spread of contagious diseases, 1 – contagious diseases are poorly controlled; spatially this range does not exceed the area of the ecosystem, 2 – spread of contagious diseases is highly controlled; spatially this range is of local importance (<i>gmina</i>), 3 – the ecosystem does not allow the spread of contagious diseases	2	2
28	Aesthetic value	0 – low aesthetic values of the ecosystem due to large urban areas, 1 – some aesthetic value due to intensive built-up area and low biodiversity, 2 – ecosystem diverse in terms of vegetation and buildings – high aesthetic values, 3 – the lake ecosystem plays a key role in the aesthetics of a specific place or architectural object	2	2
32	Tourism and recreation	0 – the lake has no beach, 1 – due to "wild" beaches the ecosystem is of little importance as a tourist and recreational site, 2 – the ecosystem is important for tourism and leisure due to the presence of several beaches, 3 – the ecosystem plays an important role in the development of tourism and recreation due to the presence of a managed beach	2	2
37	Hydrological cycle	0 – ecosystem does not take part in the hydrological cycle, 1 – ecosystem takes part in the hydrological cycle on a local scale, 2 – ecosystem takes part in the hydrological cycle on a regional scale 3 – ecosystem takes part in the hydrological cycle on a wider scale	2	2
			10	10

The newly adopted criteria show the value of ecosystem services of the lakes selected for the analysis in a different light. These values are low, with Lake Trzesiecko obtaining 7 out of 15 points and Lake Wielimie – 3 out of 15 points (Table 4, Fig. 4). The low value of ecosystem services indicates their poor quality. A particularly low value for the recreational services needs was calculated for the ecosystem of Lake Wielimie. This was due to unclassified water quality, lack of basic sanitation and unfavourable morpho-lithological conditions of the beach as well as high accessibility of the

beach for tourists and animals. Therefore, the beach on Lake Wielimie is not suitable for use as a bathing place. In turn, Lake Trzesiecko can be a bathing place, but only in the absence of blue-green algae. Despite its recreational development the problem here is the cleanliness of the beaches. Openness of the beaches and birds feeding means the aesthetics of these public places discourages recreation, hence the reasonable value of 7 out of 15 points. Low values of services indicate little chance of using them.

Table 4. Proposal of post-valuation of services of the ecosystems of Lakes Trzesiecko and Wielimie on the basis of the results of bacteriological contamination

No.	Service	Scale	Lake Trzesiecko	Lake Wielimie
12	Water	0 – over 500 FC/100 ml of the water; 1 – 200-500 FC/100 ml of the water; 2 – 100 to 200 FC/100 ml of the water; 3 – below 100 FC/100 ml of the water	1	0
19	Contamination disease spread control	0 – the beach ecosystem is diverse morphologically and lithologically, the surroundings is undeveloped; 1 – the beach ecosystem is slightly varied in terms of relief and lithology, undeveloped; 2 – beach ecosystem is artificial with a small slope, partly developed; 3 – the beach ecosystem is natural, cut off from animals with buildings which does not allow the spread of contagious diseases	2	1
28	Aesthetic value	0 – the bathing area and its surroundings does not provide aesthetic values, e.g. there is litter, rushes, excrement; 1 – in many places on the beach and in its surrounded there is litter, excrement, etc.; 2 – the ecosystem has a high aesthetic value, but there is some litter; 3 – the ecosystem plays a key role in the aesthetics of a particular place or architectural object	1	1
32	Tourism and recreation	0 – the ecosystem does not play a recreation function due to lack of toilets, 1 – the ecosystem serves a limited recreational function (one toilet per a few hundred people), 2 – the ecosystem is important for tourism and leisure (one toilet per a few dozen people); 3 – the ecosystem plays an important role in the development of recreation in the immediate vicinity of the ecosystem; several thousand people use a few toilets	2	0
37	Hydrological cycle	0 – due to its location in the urban-agricultural basin without regulated sewage situation, the ecosystem increases the likelihood of contamination, 1 – due to its location in the urban or agricultural basin, the ecosystem can affect the transport of bacteria in the water cycle, 2 – due to its location in the industrial-forest basin, the ecosystem contributes little to the spread of bacteria, 3 – due to its location in the forest catchment, the ecosystem has little effect on the hydrological cycle	1	1
			7	3

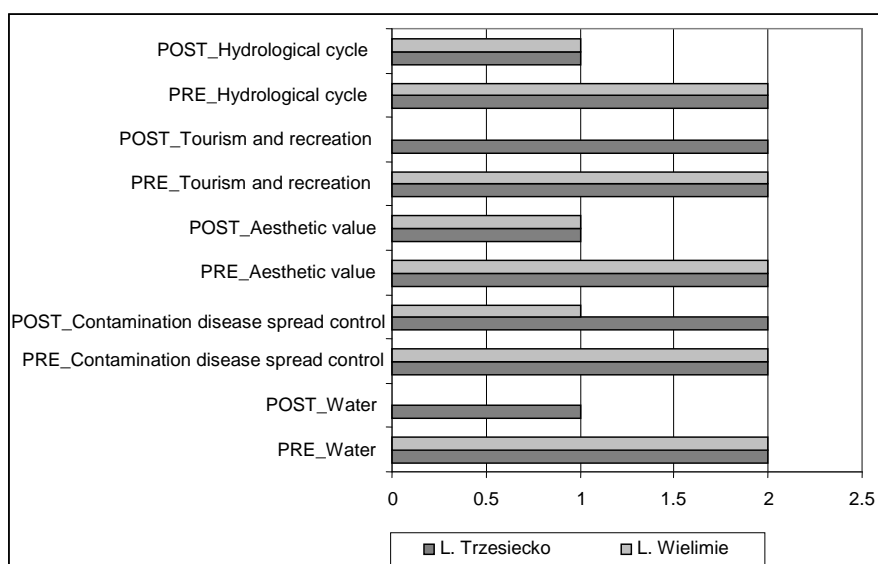


Fig. 4. Pre-valuation and post-valuation of services of the ecosystems of Lakes Trzesiecko and Wielimie on the basis of the results of bacteriological contamination

5. Discussion and conclusions

Such large differences in the service values of the ecosystem of the two lakes show the problem of selecting the appropriate valuation criteria that

reflect the actual assessment of the services. The criteria proposed by [BERNACIAK & CICHÓN \(2012\)](#) relate primarily to the quantitative criterion, while the new proposal is based on qualitative criteria related to the sanitary state of the lake, its shore

zone and its catchment area. This is not about deprecating quantitative criteria; however, in the case of recreational benefits they do not show the actual value. Taking into account only the number of beaches we indicate that such services exist, however, the possibility of using them is shown by the qualitative criteria, e.g. sanitary or morpholithological conditions of the beach. A similar situation applies to the valuation of the lake water quality. Theoretically, there is a lake, but due to exceeded norms we cannot use it because it is a health hazard. So the real value of these ecosystems is much lower than initially expected from using only quantitative criteria. Contamination of the lakes Trzesiecko and Wielimie makes it impossible to increase the value of their ecosystem services. Changing the value of the services is possible for those lakes which have high water quality with low development.

It is worth noting that the reduced value of the services of lake ecosystems even by 50% is not only the result of human pressure, the cases of industrial wastewater discharges (Lake Wielimie) and inflow of polluted waters from agricultural areas (Lake Trzesiecko with the Radacki Canal), but also due to a lack of awareness among citizens and local authorities. The beach users should care about the cleanliness of the beaches and observe bans on dogs and feeding birds. In turn, the local authorities have to take care of basic sanitation infrastructure, even if the littoral zone is used only for bathing. They should think about providing information boards which inform the users about the sanitary condition of the beach. Even small investments will help to retain the current value of services and will not cause further devastation of the littoral zones of the lake, which – according to MUELLER ET AL., (2016) – the authorities managing the lake's ecosystem often forget.

The value of ecosystem services of lakes, irrespective of the region studied, should consider anthropogenic factors. Human activity affects not only the functioning of the environment, but also the quantity and quality of its ecosystem services. It can be assumed that small anthropopression causes an increase in the supply of services and consequently contributes to an increase in their value. After exceeding a certain maximum level, especially in degraded ecosystems, the benefits offered by the ecosystem are gradually reduced.

With a decline in the number and quality of services, the declared willingness to bear the costs of maintaining a particular ecosystem declines over time (BERNACIAK & CICHON, 2012). In order to provide ecosystem services at an appropriate

level, there is a need for co-operation between different water bodies, who decide on development directions and financial contributions for environmental protection. Local authorities should also be encouraged to conduct research on the relationship between anthropopressure and ecosystem services. Determining the level of ecosystem products and services provided can help in the proper management of lake shore areas, especially those most valuable from the point of view of the services provided.

In connection with the proposed valuations of Lake Trzesiecko and Lake Wielimie, the problem of uncertainty of the valuation of the ecosystem services and its criteria appears. The uncertainty, according to WEGNER & PASCUAL (2011), may also be related to the uncertainty associated with biophysical models as well as the precision and accuracy of maps, while for HAASE ET AL. (2014) and VOLK (2013) it is a problem of the scale and its quantification. Therefore, it is worth mentioning the opinion of GOMEZ-BAGGETHUN & RIUZ-PEREZ (2011) who claim that valuation methods are not neutral. This calls for multi-dimensional assessment and value plurality. That is why it is important to focus on the development of valuation criteria in non-monetary terms and later on monetary valuation, which, according to many authors, is opposed to a holistic approach to ecosystem services.

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